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The NASA White Sands Test Facility was requested by the USAMMDA to perform an oxygen hazard analysis on the Genox CT-1 Oxygen Generation and Distribution System (OGDS), manufactured by Pacific Consolidated Industries (PCI). An oxygen hazards analysis was performed per WSTF-TP-713 and in accordance with ASTM G 63, ASTM G 88, and ASTM G 94. Several subsystems were analyzed to thoroughly investigate and identify potential oxygen-related hazards in the OGDS system. It was determined by the WSTF Oxygen Hazards Analysis Team that no major oxygen hazards exist in this system to prevent its use in the given environments. However, several recommendations were made to enhance the system's resistance to an oxygen fire and provide a safer operating environment.

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Joel Stoltzfus ____ 10 Dec 96
Joel Stoltzfus ____ Date

Contents

Figures

1.0 Introduction

Most materials, including metals, burn in oxygen-enriched environments. Because of this, potential hazards always exist in oxygen systems. Oxygen-enriched environments cause most materials to ignite at considerably lower temperatures than in air, and, once ignited, the materials have greater combustion rates. Many metals, in fact, burn violently when ignited in an oxygen-enriched environment. Also, various forms of lubricants, tapes, gaskets, fuels, and solvents can actually increase the possibility of ignition in oxygen systems.

These hazards, however, do not preclude the use of oxygen. Oxygen may be safely used in a system where all the materials are considered inflammable in their specific working environments or if the potential ignition sources are identified and controlled. These ignition and combustion hazards necessitate a proper oxygen hazards analysis before introducing a material or component into oxygen service.

Further information on the safe design of oxygen systems can be found in the most current versions of ASTM G 63, G 88, and G 94; and NASA NSS 1740.15 (1995), and NHB 8060.1C (1991), NFPA 50 (1994), NFPA 53M (1990), and CGA G-4.0 (1987), G-4.1 (1984), and G-4.4 (1984).

WSTF was requested by Mark Arnold of the USAMMDA to perform an oxygen hazard analysis on the Genox CT-1 Oxygen Generation and Distribution System (OGDS), manufactured by Pacific Consolidated Industries (PCI). PCI has manufactured and supplied this OGDS to various military field hospitals used around the world. The system has been considered from a functional and operational standpoint by the U.S. Army and approved for use in field medical hospitals. However, as a prerequisite to procurement, an oxygen hazards analysis will be performed to thoroughly investigate and identify potential oxygen-related hazards in the system.

2.0 Objective

The objective is to perform an oxygen hazards analysis on specified components of the Genox CT-1 Oxygen Generation and Distribution System.

3.0 Approach

The oxygen hazards analysis approach is shown in Figure 1 and discussed at length in TP-WSTF-713 (Dees and Poe 1993). This approach is consistent with ASTM G 88, G 63, and G 94 (1991) for analyzing the hazards of components and systems exposed to oxygen-enriched environments. The approach is based on the premise that a fire will usually not occur in any environment unless the construction materials of the system or component are flammable and a credible ignition mechanism is present.

The flammability of the component materials is first reviewed to determine if any fire hazards exist at the worst-case operating conditions. If the material is flammable, then the possible ignition mechanisms are surveyed to determine which are credible. If data for the

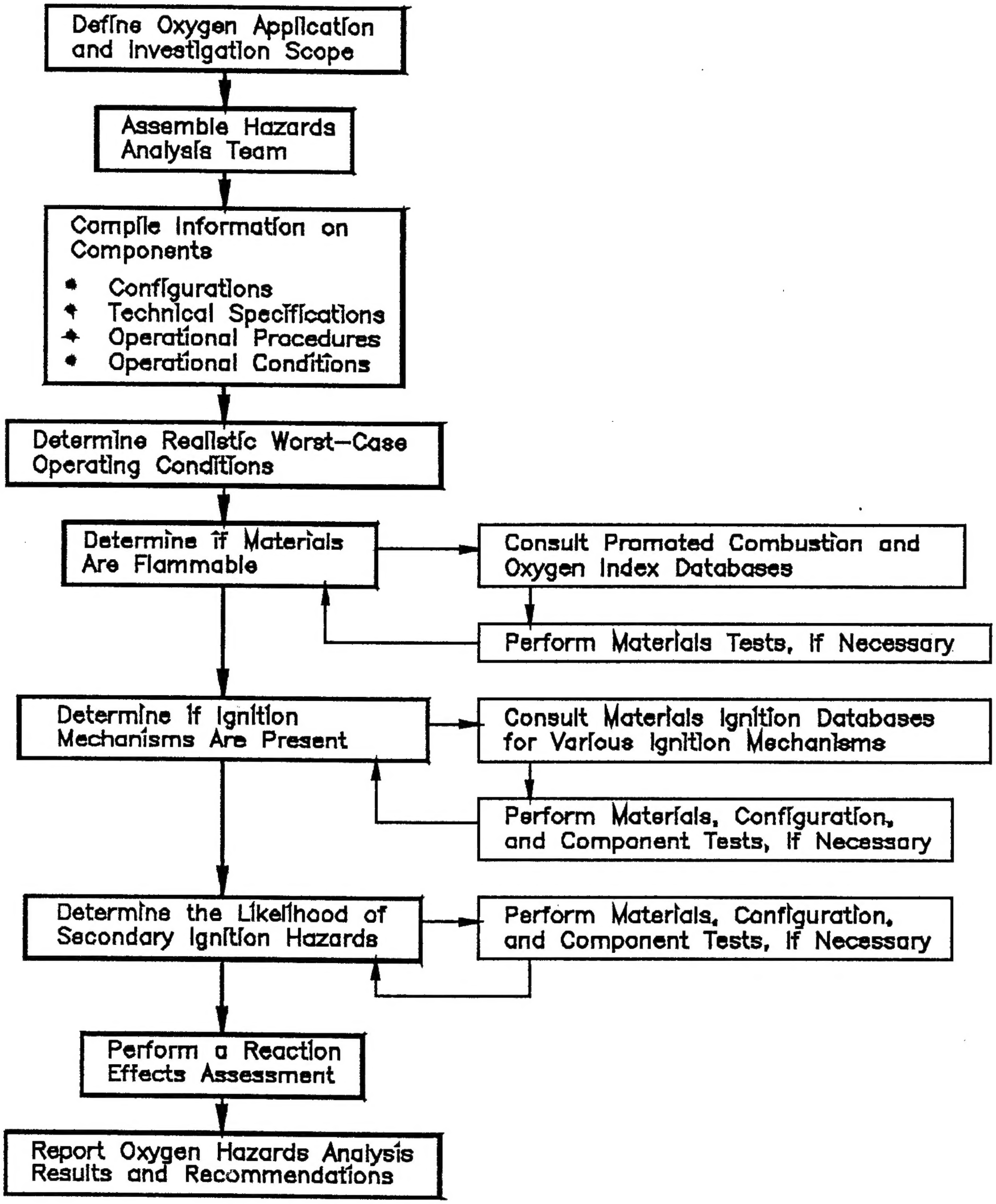


Figure 1
Approach to Oxygen Hazards Analysis

appropriate materials tests may be conducted. Finally, the secondary and reaction effects are evaluated to determine what effect an ignition and possible combustion would have on the system and the facility.

To use this oxygen hazards analysis as a tool, individual analysis charts are recorded for each component or group of components. These charts contain the component designation, the flammability of component materials (metals and soft goods), the possible ignition mechanisms, the probability of each ignition mechanism occurring in the component, and the results of the secondary effects analysis and the reaction effects assessment. The documentation also includes any recommendations or limitations that the oxygen hazards team decides on, including recommendations of further testing if needed, stipulations of use, and any additional safety precautions. If component tests are required, these tests may be performed according to the Guide for Oxygen Component Qualification Tests (Bamford and Rucker 1992).

4.0 Component Description

The Genox CT-1 OGDS is comprised of a series of subsystems. The subsystems include a liquid oxygen (LOX) production plant, a LOX buffer storage tank (BST), a cylinder fill system (CFS), a high-speed recharger, a recharger oxygen support equipment system (ROSE I or ROSE II), a patient oxygen distribution system (PODS), a surgical suite oxygen distribution system (SSODS), and a hospital oxygen backup system (HOBS). Figure 2 shows the operational flow diagram of these subsystems.

Several of these subsystems are similarly configured, but are used in different operations. Two of these subsystems are the CFS and the HOBS. The HOBS is analyzed in detail as part of this hazards analysis. Therefore, the CFS is not analyzed as a separate subsystem, only through its similarity to the HOBS. Another pair of similar subsystems is the PODS and the SSODS. The PODS is analyzed as part of this hazards analysis, while the SSODS is analyzed only through its similarity to the PODS. The detailed analysis of the ROSE I also covers the components of the ROSE II. Additionally, the LOX Plant is not considered in this hazards analysis. In summary, this analysis will consider the following subsystems in this order: the ROSE I (Figure 3), HOBS (Figure 4), PODS (Figure 5), BST (Figure 6) and the high-speed Recharger (Figure 7).

The BST is a 400-gallon LOX tank on a truck, used to transport LOX from distant LOX sources to the general vicinity of the field hospitals. The ROSE I subsystem is primarily responsible for transporting LOX from the BST to the field hospital and converting it to oxygen gas before distribution. It is comprised of a 119-gallon cryo-container for transportation, a passive vaporizer for low-pressure oxygen, a LOX pump and vaporizer for high-pressure oxygen, and a vacuum pump for evacuating oxygen cylinders. The HOBS subsystem contains two central manifolds responsible for filling eight "H" cylinders and ten "D" cylinders with high-pressure oxygen gas. The HOBS contains a hospital reserve kit (HRK) which reduces the pressure of the oxygen before delivering it to the hospital. The high-speed recharger is a subsystem used for quickly converting LOX to high-pressure gaseous oxygen (GOX) for the CFS.

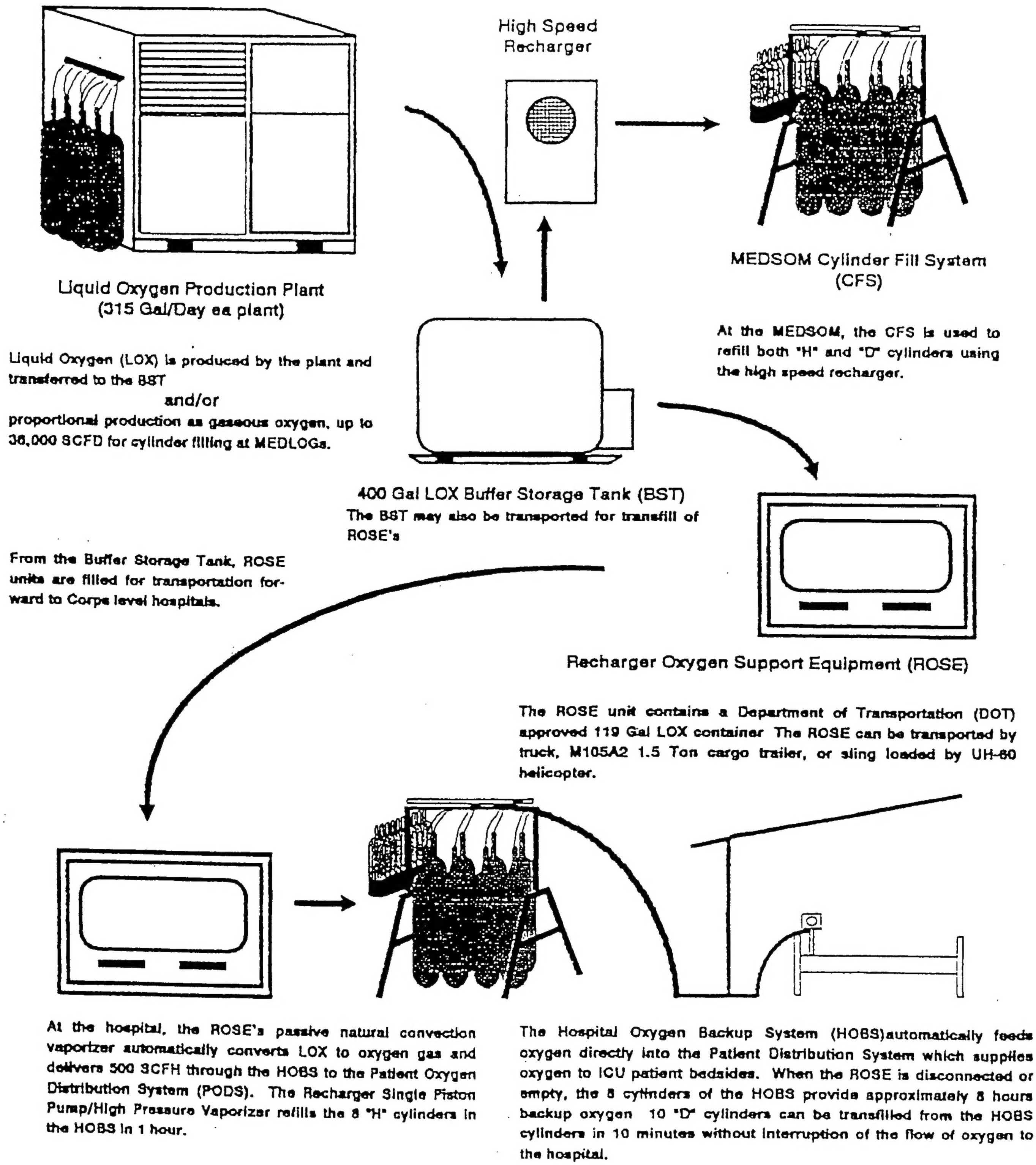
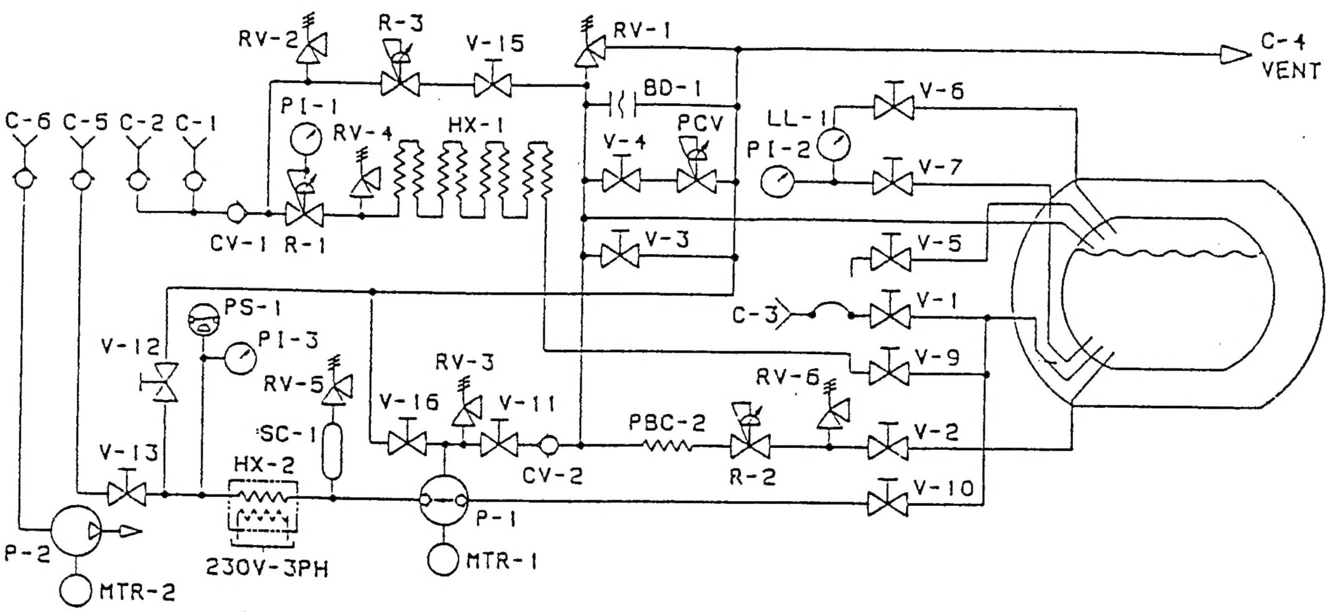


Figure 2
Genox CT-1 OGDS Operational Flow Diagram

FLOW DIAGRAM



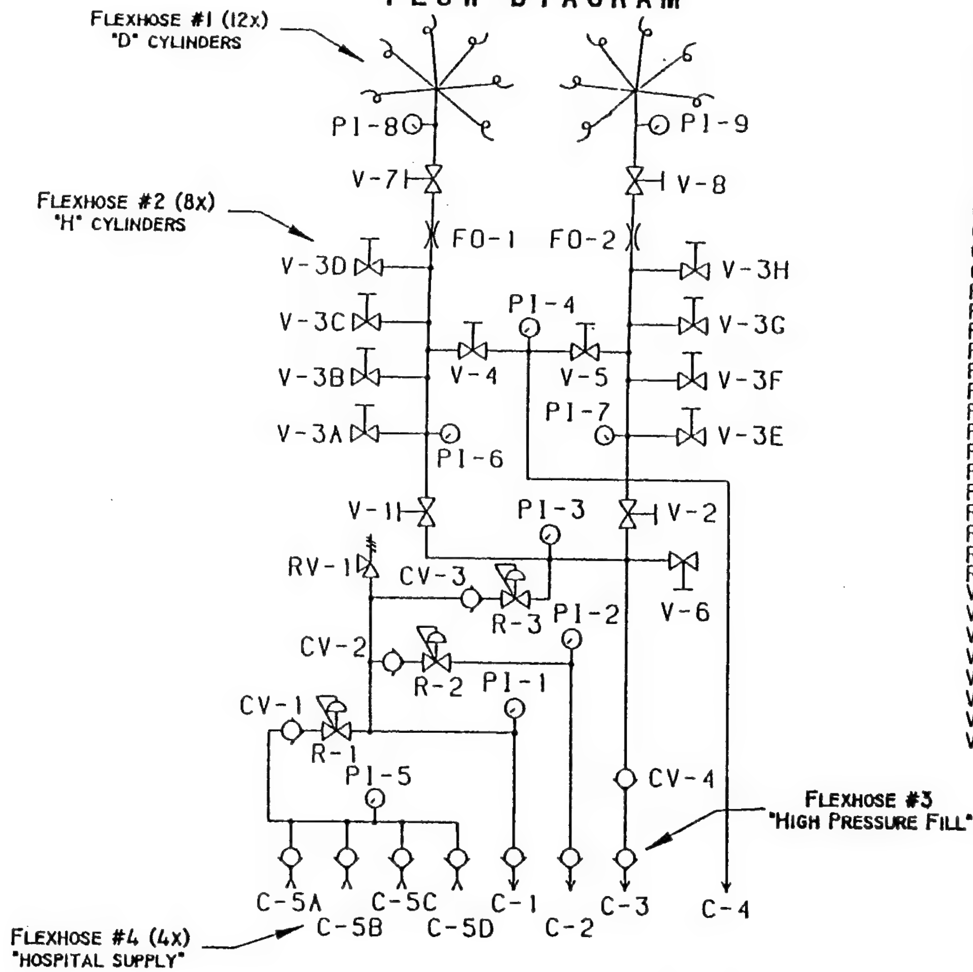
NOMENCLATURE

SYMBOL	DESCRIPTION
BD-1	BURST DISC (INNER VESSEL 165 PSI)
C-1	CONNECTION (MEDICAL OXYGEN)
C-2	CONNECTION (MEDICAL OXYGEN)
C-3	CONNECTION, LIQUID FILL
C-4	CONNECTION, VENT
C-5	CONNECTION, H.P. OXYGEN SUPPLY
C-6	CONNECTION, VACUUM
CV-1	CHECK VALVE, HOSPITAL O_2 SUPPLY
CV-2	CHECK VALVE, VENT TO TANK
HX-1	HEAT EXCHANGER, LOW PRESSURE
HX-2	HEAT EXCHANGER, HIGH PRESSURE
LL-1	LIQUID LEVEL GAUGE
MTR-1	MOTOR, H.P. PUMP
MTR-2	MOTOR, VACUUM PUMP
P-1	PUMP, HIGH PRESSURE
P-2	PUMP, VACUUM
PBC-2	PRESSURE BUILDING COIL (EXTERNAL)
PCV	ROADING REGULATOR (35 PSI)
PI-1	PRESSURE GAUGE O_2 DELIVERY (0-200)
PI-2	PRESSURE GAUGE TANK (0-200)
PI-3	PRESSURE GAUGE (0-5000)
PS-1	PRESSURE SWITCH (2250 PSI)
R-1	PRESSURE REGULATOR (MEDICAL OXYGEN 60-100 PSI)

SYMBOL	DESCRIPTION
R-2	PRESSURE BUILDING REGULATOR (100 PSI)
R-3	ECONOMIZER REGULATOR (105 PSI)
RV-1	RELIEF VALVE (INNER VESSEL 115 PSI)
RV-2	RELIEF VALVE (150 PSI)
RV-3	RELIEF VALVE, H.P. PUMP VENT (150 PSI)
RV-4	RELIEF VALVE (150 PSI)
RV-5	RELIEF VALVE, HIGH PRESSURE (2500 PSI)
RV-6	RELIEF VALVE (150 PSI)
SC-1	SURGE CHAMBER
V-1	VALVE, LIQUID FILL
V-2	VALVE, PRESSURE BUILDING
V-3	VALVE, TANK VENT
V-4	VALVE, PRESSURE CONTROL - ROADING
V-5	VALVE, FULL TRYCOCK
V-6	VALVE, LOW PRESSURE - GAUGE
V-7	VALVE, HIGH PRESSURE - GAUGE
V-9	VALVE, GAS USE (OXYGEN SUPPLY VALVE)
V-10	VALVE, H.P. PUMP SUPPLY
V-11	VALVE, H.P. PUMP VENT TO TANK
V-12	VALVE, H.P. PUMP PRIME
V-13	VALVE, H.P. GASEOUS O_2 SUPPLY
V-15	VALVE, ECONOMIZER ISOLATION
V-16	VALVE, H.P. PUMP VENT TO ATMOSPHERE

Figure 3
Recharger Oxygen Support Equipment Subsystem

FLOW DIAGRAM



SYMBOL		DESCRIPTION
C-1	—	CONNECTION, PRIMARY ROSE
C-2	—	CONNECTION, SECONDARY ROSE
C-3	—	CONNECTION, HOBS FILL-HIGH PRESSURE
C-4	—	CONNECTION, VACUUM
C-5A-D		CONNECTION, HOSPITAL OXYGEN SUPPLY
CV-1	—	CHECK VALVE, PRIMARY ROSE
CV-2	—	CHECK VALVE, SECONDARY ROSE
CV-3	—	CHECK VALVE, HOBS SUPPLY
CV-4	—	CHECK VALVE, HOBS FILL
FO-1	—	FLOW ORIFICE, D-CYLINDER RACK-LEFT
FO-2	—	FLOW ORIFICE, D-CYLINDER RACK-RIGHT
PI-1	—	PRESS. IND. PRIMARY (0-200 PSI)
PI-2	—	PRESS. IND. SEC. ROSE (0-200 PSI)
PI-3	—	PRESS. IND. HOBS SUPPLY (0-4000 PSI)
PI-4	—	PRESS. IND. VAC. (30 HG-15 PSI)
PI-5	—	PRESS. IND. HOSP. O2 SUPPLY (0-200 PSI)
PI-6	—	PRESS. IND. MAN-LEFT (0-4000 PSI)
PI-7	—	PRESS. IND. MAN-RIGHT (0-4000 PSI)
PI-8	—	PRESS. IND. MAN-LEFT D-CYL. RACK (0-5000 PSI)
PI-9	—	PRESS. IND. MAN-RIGHT D-CYL. RACK (0-5000 PSI)
R-1	—	REGULATOR, HOSPITAL USE (60 PSI)
R-2	—	REGULATOR, SECONDARY ROSE (80 PSI)
R-3	—	REGULATOR, HOBS SUPPLY (75 PSI)
RV-1	—	RELIEF VALVE (200 PSI)
V-1	—	VALVE, MANIFOLD-LEFT
V-2	—	VALVE, MANIFOLD-RIGHT
V-3A-H		VALVE, CYLINDERS-HIGH PRESSURE
V-4	—	VALVE, VACUUM-LEFT
V-5	—	VALVE, VACUUM-RIGHT
V-6	—	VALVE, VENT
V-7	—	VALVE, MANIFOLD-LEFT, D-CYLINDER RACK
V-8	—	VALVE, MANIFOLD-RIGHT, D-CYLINDER RACK

Figure 4
Hospital Oxygen Backup System

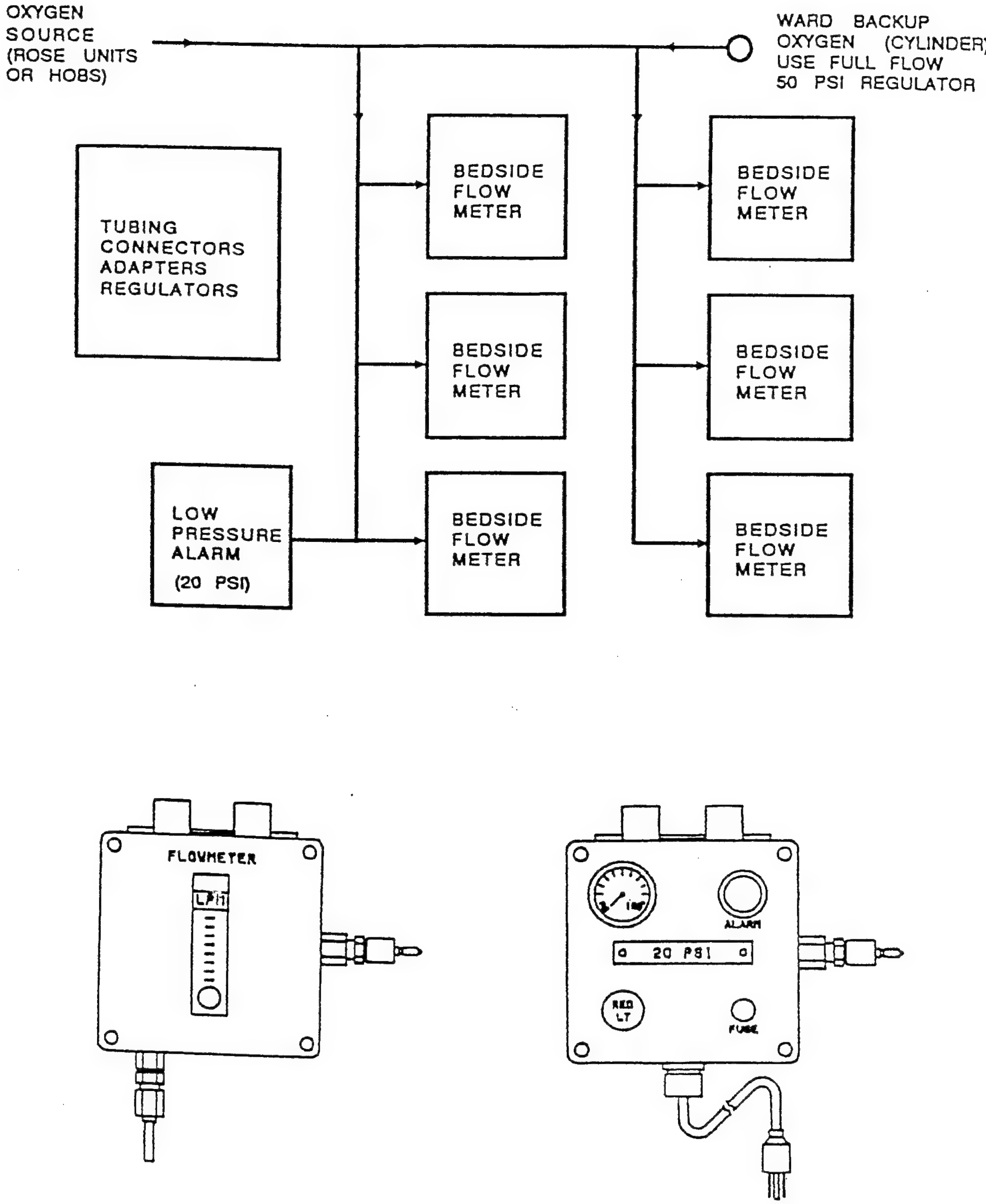
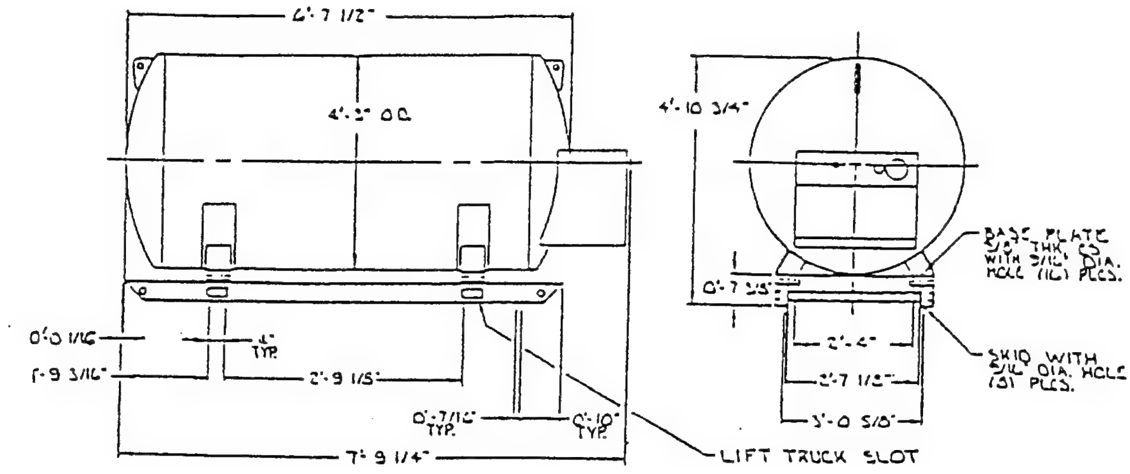


Figure 5
Patient Oxygen Distribution System



SPECIFICATIONS

TANK DESIGN

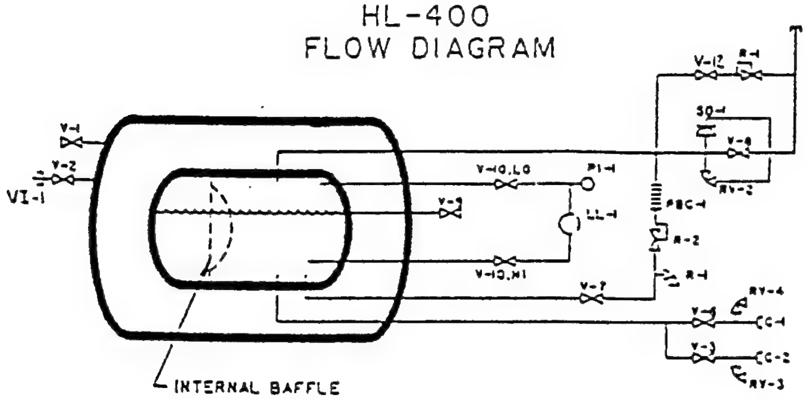
1.) INNER VESSEL .... ASME CODE, SECTION VIII DIVISION I
MAWP .... 50 PSI
VOLUME (GALLONS) .... 400 NET
.... 440 GROSS
MATERIAL .... T304 SA240 STAINLESS STEEL
DESIGN TEMP .... -320 TO +100 F

2.) OUTER VESSEL .... FULL VACUUM PER CGA 341
MATERIAL .... A36 CARBON STEEL
DESIGN TEMP .... -20 TO +300 F

3.) INSULATION .... VACUUM AND SUPER INSULATION

4.) WEIGHT EMPTY .... 1763 LBS
FULL OXYGEN .... 5574 LBS
NITORGEN .... 4461 LBS

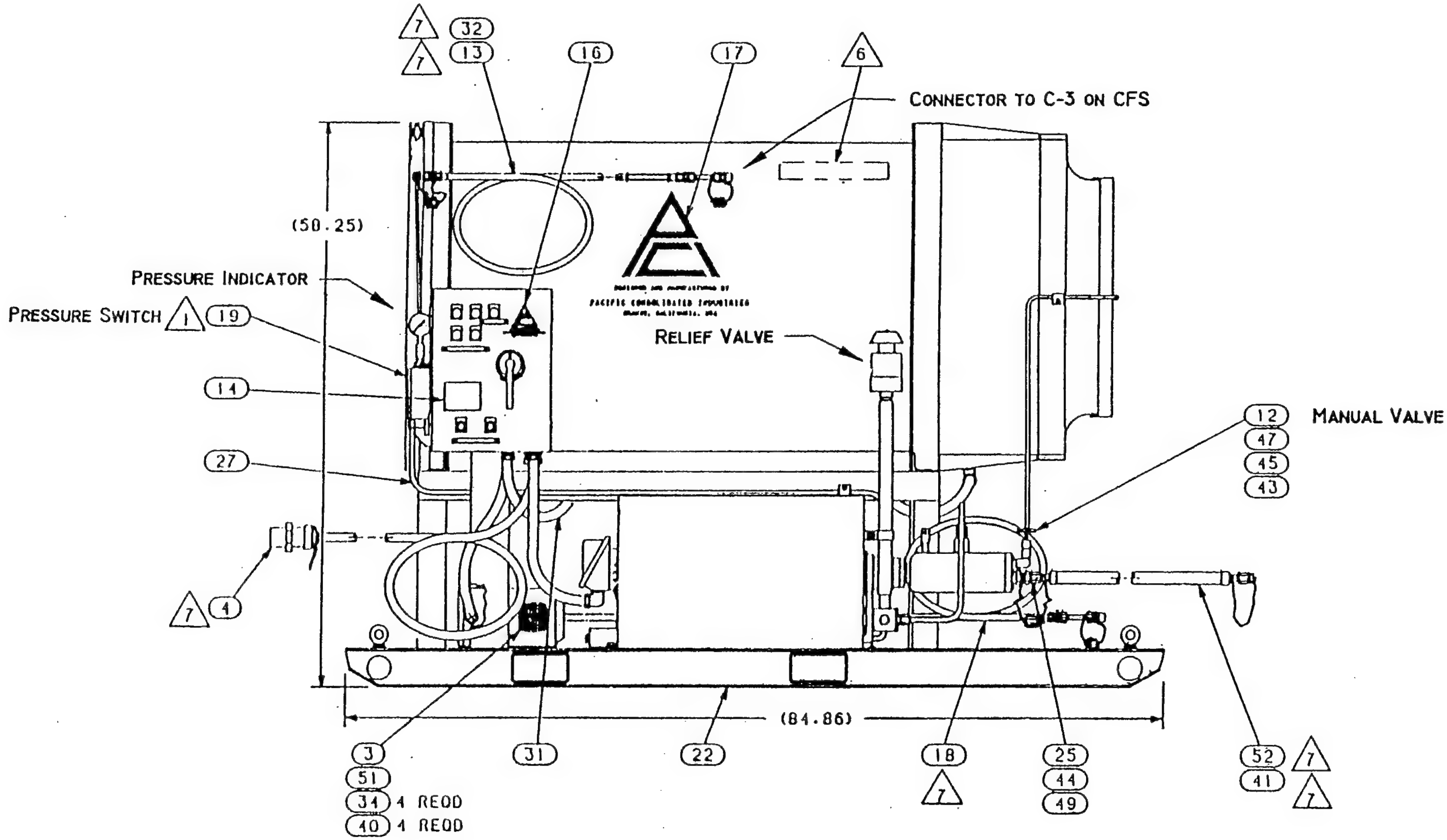
HL-400 FLOW DIAGRAM



NOMENCLATURE

V-1	VALVE, VACUUM SEAL OFF	PI-1	PRESSURE INDICATOR, INNER VESSEL
V-2	VALVE, VACUUM PROBE	R-1	REGULATOR, OVER THE ROAD
V-3	VALVE, SERVICE LINE	R-2	REGULATOR, PRESSURE BUILDING
V-6	VALVE, FILL DRAIN	RV-1	RELIEF VALVE, LINE
V-7	VALVE, PRESSURE BUILD UP	RV-2	RELIEF VALVE, INNER VESSEL
V-8	VALVE, VENT	RV-3	RELIEF VALVE, SERVICE LINE
V-9	VALVE, FULL TRYCOCK	RV-4	RELIEF VALVE, FILL LINE
V-10 HI	VALVE, HIGH PRESSURE GAUGE	SD-1	SAFETY DISC, INNER VESSEL
V-10 LO	VALVE, LOW PRESSURE GAUGE	PBC-1	PRESSURE BUILDING COIL
		VI-1	VACUUM PROBE
V-12	VALVE, OVER THE ROAD REGULATOR	C-1	CONNECTION, FILL-DRAIN
LL-1	LIQUID LEVEL INDICATOR	C-2	CONNECTION, SERVICE LINE

Figure 6
Liquid Oxygen Buffer Storage Tank



SIDE VIEW

Figure 7
High-speed Recharger

5.0 Results and Discussion

5.1 ROSE I System

The ROSE I subsystem is shown in Figure 3. LOX, at a maximum pressure of 120 psig (0.83 MPa), flows from the storage tank through either a low-pressure line or a high-pressure line. The low-pressure line has a passive heat exchanger, HX-1, which vaporizes the gas before it passes through regulator R-1. The high-pressure line has a LOX pump, P-1, which pumps high-pressure LOX into HX-2. High-pressure GOX flows through valve V-13 and out to the HOBS.

A summary of the hazards analysis performed on the ROSE I is shown in Chart 1. Each component listed was analyzed in the hazards analysis and is discussed below. The following legends apply to all hazards analysis charts in this discussion:

Material Flammability	**Ignition Hazards**	**Secondary Effect**	**Reaction Effect**
F = Flammable	0 = Almost Impossible	+ = Analysis of Affected Components Needed	A = Negligible
N = Nonflammable	1 = Remotely Possible	- = No Further Analysis Needed	B = Marginal
	2 = Possible		C = Critical
	3 = Probable		D = Catastrophic
	4 = Highly Probable		

The material flammability legend applies to the metals and soft goods columns in the hazards analysis charts. The ignition hazards legend applies to the frictional heating column through the kindling chain column. The secondary effect legend is for the secondary effect column, and the reaction effect legend applies to the reaction effect column.

The accumulator in this system, shown as SC-1 in Figure 3, was treated as if it were a section of stainless steel tubing. Therefore, no hazards analysis discussion is included for this component.

5.1.1 Manual Valves V-1, V-2, V-3, V-9, V-10

These manual valves are all of the same configuration, but are used for different applications. V-1 is the liquid fill valve; V-2 is the pressure building valve; V-3 is the tank vent valve; V-9 is the main oxygen supply valve; V-10 is the high-pressure pump supply valve. These are bronze cryogenic globe valves, designed for oxygen service. Each of these valves has a worst-case operating pressure of 115 psig (0.79 MPa) and temperature of ambient to cryogenic oxygen temperature.

Chart 1
Summary of Hazards Analysis for the ROSE I

Recharger Oxygen Support Equipment (ROSE)	Metals	Soft Goods	Frictional Heating	Adiabatic Compression	Mechanical Impact	Particle Impact	Mechanical Stress	Static Discharge	Electrical Arc	Chemical Reaction	Resonance	Other Ignition Mechanisms	Kindling Chain	Secondary Effect	Reaction Effect
Valves: V-1, V-2, V-3, V-9, V-10	N	F	0	0	0	1	0	0	0	0	0	0	0	+	C
Valves: V-4, V-5, V-11, V-15, V-16	N	F	0	0	0	1	0	0	0	0	0	0	0	-	C
Valves: V-6, V-7	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C
Valves: V-12, V-13	F	F	0	0	0	2	0	0	0	0	0	0	2	-	C
Regulator: R-2	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C
Regulators: PCV, R-3	N	F	0	0	0	0	0	0	0	0	0	0	0	+	C
Regulator: R-1	N	F	0	0	0	0	0	0	0	0	0	0	2	-	C
Relief Valves: RV-1, 2, 3, 4, 6	N	F	0	0	0	0	0	0	0	0	0	0	1	+	C
Pressure Indicator: PI-1, PI-2	N	-	0	0	0	0	0	0	0	0	0	1	0	-	C
Liquid Level Guage: LL-1	F	F	0	0	0	0	0	0	0	0	0	0	2	-	C
Pressure Indicator: PI-3	F	-	0	0	0	0	0	0	0	0	0	0	3	-	C
Pressure Switch: PS-1	F	-	0	0	0	0	0	0	0	0	0	0	3	-	C
Relief Valve: RV-5	F	F	1	0	0	2	0	0	0	0	0	0	1	-	C
Check Valve: CV-2	N	-	0	0	0	0	0	0	0	0	0	0	0	-	C
Check Valve: CV-1	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C
Connections: C-1, C-2, C-6	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C
Connection: C-5	F	F	0	0	0	0	0	0	0	0	0	2	1	-	C
Pump: P-1	F	F	1	0	0	0	0	0	0	0	0	0	1	-	C
Heat Exchangers: HX-1, HX-2	F	-	0	0	0	1	0	0	0	0	0	0	3	-	C
Burst Disc: BD-1	N	-	0	0	0	0	0	0	0	0	0	0	0	+	C

5.1.1.1 Material Flammability of Metals and Soft Goods

The metal parts of these valves include a bronze valve body, bonnet, and bonnet ring, a brass bonnet nut, and a 300 series stainless steel valve stem. The metals are considered *nonflammable* in the given worst-case operating environment. The soft goods include a PCTFE valve seat and a 25-percent glass-filled PTFE bonnet bearing and gasket. The soft goods are considered *flammable* in the worst-case operating environment.

5.1.1.2 Ignition Mechanisms

The only potential ignition mechanism is particle impact. Particle impact is considered *remotely possible*. These valves do not have upstream filters and the PCTFE seat material is vulnerable. However, direct impingement of a particle on the seat is not likely due to valve configuration. The remainder of the ignition mechanisms are considered *almost impossible*.

5.1.1.3 Secondary Effect

If any of these valve components failed by external leakage, the ROSE I's internal housing would become oxygen-enriched. Further analysis should be done on the electrical contacts of heat exchanger HX-2 to determine if an ignition hazard exists.

5.1.1.4 Reaction Effect

If this component caught fire and burned, damage to the component could be *critical*. A rating of *critical* implies that damage to the component could mean loss of capability and equipment, but no loss of human life. This reaction effect rating applies to all components considered in this analysis.

5.1.2 Manual Valves V-4, V-5, V-11, V-15, V-16

Manual valve V-4 is the *roading* pressure control valve; V-5 is the full trycock valve; V-11 is the high-pressure vent-to-tank valve; V-15 is the economizer isolation valve; V-16 is the high-pressure pump vent-to-atmosphere valve. These valves are also brass cryogenic globe valves. The worst-case operating conditions are 115 psig (0.79 MPa) and ambient to cryogenic oxygen temperature.

5.1.2.1 Material Flammability of Metals and Soft Goods

The oxygen-wetted metals in these valves include a brass valve body, bonnet, and bonnet nut, and a silicon brass valve stem. These metals are considered *nonflammable* in the given worst-case operating environment. The soft goods include a PCTFE seat and a 25-percent, glass-filled PTFE bonnet bearing. These materials are *flammable* in the given worst-case environment.

5.1.2.2 Ignition Mechanisms

Again, the only *remotely possible* ignition mechanism is particle impact. The PCTFE seat is vulnerable to ignition if struck directly by a fast moving particle. However, this scenario is

unlikely due to the valve seat configuration. All other ignition mechanisms for these valves are considered *almost impossible.*

5.1.3 Manual Valves V-6, V-7

Manual valve V-6 is the low-pressure gauge valve; V-7 is the high-pressure gauge valve. These are screwed-bonnet, rotating-seal needle valves that act as gauge isolation valves for the ullage pressure inside the LOX tank. There is relatively no gas flow through the valves. The worst-case operating conditions are 115 psig (0.79 MPa) and ambient to cryogenic oxygen temperature.

5.1.3.1 Material Flammability of Metals and Soft Goods

The metal parts of these valves include a brass body and silicon bronze stem. These metals are *nonflammable* in the given worst-case environments. The soft goods include a TFE-coated stem tip and virgin Teflon®[1] packing. These materials are *flammable* if ignited in the given conditions.

5.1.3.2 Ignition Mechanisms

Because of their benign application and environment, these valves have no recognizable ignition mechanisms.

5.1.4 Manual Valves V-12, V-13

Manual valve V-12 is the high-pressure pump prime valve; V-13 is the high-pressure GOX supply valve. These valves are bonnet needle valves that operate to shut-off the discharge and vent pump P-1. The worst-case pressure to these valves is 2500 psig (17 MPa). The temperature is approximately ambient.

5.1.4.1 Material Flammability of Metals and Soft Goods

The metals in these valves include a brass body and packing nut and a 316 stainless steel stem. The stem is considered *flammable* at this high-pressure operating condition. The soft goods include a CTFE (Kel-F®[2]) stem tip, and Teflon stem packing. Teflon is *flammable* if ignited under these operating conditions.

5.1.4.2 Ignition Mechanisms

Frictional heating is an *almost impossible* ignition hazard because, though the seat is rotating as it seals, the loads are too small for ignition to occur.

---

[1] Teflon® is a registered trademark of DuPont de Nemours.

[2] Kel-F® is a registered trademark of 3M.

Particle impact is the only ignition mechanism of concern. The ignition hazard rating is *possible* because the Kel-F seat is vulnerable to ignition if impacted by ignitable particles at this pressure and fluid velocity. The ignition rating is not more severe because impacting the Kel-F seat is a secondary impact and operationally unlikely. Additionally, these conditions are less severe than those shown to ignite these materials. Also, these valves demonstrate a long history of use with no known fires.

Kindling chain is a *possible* ignition source for parts surrounding V-12 and V-13 because the stem is stainless steel and flammable in this environment. If ignition occurred in the valve seat, the stem would be vulnerable to ignition. History shows that Kel-F will ignite stainless steel under these conditions.

5.1.5 Regulator R-2

Regulator R-2 is the pressure building regulator. It is a back pressure regulator that functions to regulate the pressure in the LOX tank. If the liquid head drops below the set pressure, the regulator opens, allowing liquid to flow through the regulator, vaporize in the pressure building coil, PBC-2, and pressurize the gas head in the tank. The worst-case operating pressure is 120 psig (0.82 MPa).

5.1.5.1 Material Flammability of Metals and Soft Goods

The metals in R-2 include a brass body and spring chamber, a bronze diaphragm, and a stainless steel pressure spring. These materials are considered *nonflammable* in the given worst-case environment. The soft goods in R-2 include a Teflon seat disc and diaphragm gasket. Teflon is *flammable* in this environment.

5.1.5.2 Ignition Mechanisms

No credible ignition mechanisms were found in regulator R-2. The pressurization rate is too low for adiabatic compression to be an issue, and the fluid velocities are too low for particle impact ignition.

5.1.6 Regulator R-3, PCV

Regulator R-3 is the economizer regulator, and the PCV is the *roading* regulator. These components are back-pressure regulating valves. PCV is used as a relief device during transportation of the ROSE I. If the pressure in the line upstream of manual valve V-4 builds greater than the set pressure, the pressure force overcomes the spring force of the regulator and the poppet lifts off its seat, allowing gas to vent. The function of R-3 is to reduce the specific line pressure before oxygen gas is delivered to the HOBS. The worst-case operating pressure for the PCV is 35 psig (0.24 MPa) at the inlet, and atmospheric pressure out. The worst-case pressure for regulator R-3 is 105 psig (0.72 MPa) at the inlet and 90 psig (0.62 MPa) at the outlet.

5.1.6.1 Material Flammability of Metals and Soft Goods

The metals of these regulating valves include a bronze body, spring chamber, and diaphragm, and a stainless steel seat disc, seat ring, and pressure ring. These metals are considered *nonflammable* at the given worst-case operating conditions. The only soft good in the valves is a Teflon diaphragm gasket. Teflon is *flammable* in these conditions.

5.1.6.2 Ignition Mechanisms

No credible ignition mechanisms were found for these components in their respective environments.

5.1.6.3 Secondary Effect

There is a possibility of contaminating the LOX tank of the ROSE I if the PCV failed open, allowing air or moisture to build up in tank. Consequently, contamination happens even during normal filling operations with impurities in the LOX. Hence, procedures should be implemented for detailed maintenance of the tank, most importantly, purging the tank on a regular basis. It is recommended that this issue be investigated. However, this is ultimately a purity issue for the breathing gas, not a flammability issue.

5.1.7 Regulator R-1

Regulator R-1 is the medical oxygen pressure regulator. The function of this regulator is to reduce the upstream gas pressure after it vaporizes in the passive heat exchanger and is delivered to the HOBS. The worst-case inlet pressure of this component is 115 psig (0.79 MPa), and the reduced outlet pressure is 90 psig (0.62 MPa).

5.1.7.1 Material Flammability of Metals and Soft Goods

The metals in this component are *nonflammable* in the given worst-case operating conditions. These metals include a bronze inlet filter, a stainless steel diaphragm, and a brass body. The soft goods include a Delrin®[1] stem bushing and a polymer seat. The polymer seat material was unknown at the time of the analysis, but was analyzed as nylon to represent a worst-case scenario. These soft goods are *flammable*.

5.1.7.2 Ignition Mechanisms

All ignition mechanisms were considered *almost impossible*. Adiabatic compression data for Nylon 66 indicates that, even at 500 psi (3.4 MPa) (a higher pressure than the worst-case here), the no ignitions occurred (WSTF # 81-14598).[2] Particle impact ignition is also considered *almost impossible*. A particle, upon impact, would most likely hit the stainless steel plunger. Stainless steel is not a *flammable* metal in this configuration and at this pressure. Also, the gas does not reach sonic velocities in this application. Furthermore, the

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[1] Delrin® is a registered trademeark of DuPont de Nemours.

[2] In-house report. NASA Johnson Space Center White Sands Test Facility, Las Cruces, NM, 1981.

gas temperature is approximately 25 °F (14 °C) below ambient temperature, making ignition even more unlikely.

A kindling chain reaction is *possible* because, though no ignition mechanisms are identified, if the polymer seat ignited and burned, the stainless steel diaphragm could be ignited.

5.1.8 Relief Valves RV-1, RV-2, RV-3, RV-4, RV-6

Relief valve RV-1 is the inner vessel relief valve; RV-2 is a standard line relief valve; RV-3 is the high-pressure pump vent relief valve; RV-4 is the relief valve downstream of the passive heat exchanger HX-1, RV-6 is a relief valve for the pressure building regulator. The purpose of these relief valves is to give overpressure protection in their respective places in the ROSE I. The worst-case cracking pressure on any of these components is 150 psig (1.0 MPa). Relief valve RV-4 is the actual component analyzed because its operation is the most severe of these five components.

5.1.8.1 Material Flammability of Metals and Soft Goods

The metals in these relief valves include a brass body and spring holder, and a stainless steel spring. These metals are considered *nonflammable* in the given worst-case operating environment. The soft goods in these components include a fluorosilicone seat disc, which is *flammable* in this operating environment.

5.1.8.2 Ignition Mechanisms

Again, no ignition mechanisms were identified for the operation of these components in their given environment. Considering frictional heating of the spring holder on the body upon relief, data indicates that ignition of brass rubbing on brass in GOX occurs at approximately 3×10^{-6} lbf/in^2 x ft/min ($1\text{x}10^{-8}$ W/m^2) (NASA Hydrogen-Oxygen Safety Standards Review Committee 1995), a much greater energy than that created by this relief valve.

Kindling chain is a *remotely possible* ignition hazard if these relief valves chatter (seat/ re-seat) and particulate is generated. However, the fluid flowrates are too low for ignition of particulate to be a concern.

5.1.8.3 Secondary Effect

If relief valve RV-4 fails closed, there is a possibility of a line rupture. The adjacent heat exchanger line is aluminum, which is most susceptible to this hazard. WSTF data from a fire that occurred in the testing of a space suit for NASA indicates that fresh metal exposure of aluminum is a credible ignition source.

5.1.9 Pressure Indicators PI-1, PI-2

Pressure indicators PI-1 and PI-2 are low-pressure Bourdon tube gauges. The maximum pressure that can be exposed to these components is 115 psig (0.79 MPa) through the LOX tank or through heat exchanger HX-1.

5.1.9.1 Material Flammability of Metals and Soft Goods

The only oxygen-wetted metal in these gauges is the brass Bourdon tube. Brass is considered *nonflammable* under the given worst-case operating conditions. There are no polymers in these gauges.

5.1.9.2 Ignition Mechanisms

The only ignition mechanism considered *remotely possible* occurs if the component gets contaminated. Because traditional Bourdon tubes have a bent shape and no flow-through capabilities, they are very difficult instruments to clean for oxygen service. It can be assumed that particulate will become trapped at the dead-end of the gauge. However, because these gauges are designed for low pressure, the Bourdon tubes have a larger internal diameter and are easier to clean, making the flammability hazard less severe.

5.1.10 Liquid Level Gauge LL-1

This gauge is for the purpose of monitoring the level of LOX in the tank. The worst-case pressure exposed to the gauge is 120 psig (0.83 MPa).

5.1.10.1 Material Flammability of Metals and Soft Goods

The metals in this gauge include a die-cast aluminum casing and a stainless steel support plate and range spring. The aluminum casing is considered *flammable* in the worst-case operating environment. Data shows that the promoted combustion threshold pressure of commercially pure aluminum is 25 psia (0.17 MPa) (NASA Hydrogen-Oxygen Safety Standards Review Committee 1995). The soft goods include a silicone rubber diaphragm, which acts as a body seal. This material is *flammable* in the given operating conditions.

5.1.10.2 Ignition Mechanisms

All ignition mechanisms are considered *almost impossible* in the operating environment. It should be noted that the cleaning of this component is done by the manufacturer before shipping, and it is not re-cleaned.

Kindling chain will occur if the silicone rubber diaphragm is ignited and the fire propagates to the aluminum casing and stainless steel. Therefore, this hazard is considered *possible*.

5.1.11 Pressure Indicator PI-3

Pressure indicator PI-3 is a high-pressure Bourdon tube gauge. The worst-case pressure the gauge is exposed to is 2250 psig (15.5 MPa).

5.1.11.1 Material Flammability of Metals and Soft Goods

At 2250 psig (15.5 MPa), the metals in this gauge are considered *flammable*. The oxygen-wetted metal is the stainless steel Bourdon tube. There are no polymers to evaluate.

5.1.11.2 Ignition Mechanisms

All ignition mechanisms except kindling chain are considered *almost impossible* for this component.

Kindling chain is considered *probable* in this high-pressure setting. If oil or other hydrocarbons contaminate the dead-end of the Bourdon tube and ignite, the fire can propagate and burn the stainless steel Bourdon tube. This hazard could be eliminated by changing the Bourdon tube material to brass, or implementing a bleed port to allow flow-through cleaning in the Bourdon tube.

5.1.12 Pressure Switch PS-1

This instrument contains a Bourdon tube mechanism which triggers a pressure switch to shut off the LOX pump at low pressures. The worst-case maximum pressure is 2250 psig (15.5 MPa) at the outlet of the heat exchanger, HX-2.

5.1.12.1 Material Flammability of Metals and Soft Goods

The metal Bourdon tube in the pressure switch is fabricated of stainless steel, which is *flammable* at the worst-case operating pressure. There are no polymers exposed to the oxygen.

5.1.12.2 Ignition Mechanisms

This component is very similar in its configuration to the high-pressure Bourdon tube pressure gauge PI-3. It was analyzed as such with the same issues to be considered.

5.1.13 Relief Valve RV-5

Relief valve RV-5 acts as a pressure release to protect the accumulator and the heat exchanger HX-2 from overpressurizing. The cracking pressure is 2500 psig (17.2 MPa).

5.1.13.1 Material Flammability of Metals and Soft Goods

The metals in this relief valve include a stainless steel body and poppet, Cr-V steel belville washers, and an anodized aluminum (Type II) housing. These metals are considered *flammable* in this environment. The polymers include a Teflon TFE O-ring and silicone O-rings. Under the operating conditions, these polymers are considered *flammable*.

5.1.13.2 Ignition Mechanisms

It should be noted that this valve has an extensive history of use in many cryogenic applications. This can reduce the severity of the given ignition mechanisms. Frictional heating as a result of valve chatter is a *remotely possible* ignition hazard. Low loads and low cycle rates reduce the hazard rating. Particle impact is a *possible* source of ignition in this valve. Sonic velocities occur across the valve seat and impacts can occur against the TFE

seat or stainless steel trim. The extensive history of use demonstrates an acceptable risk level for this component.

Kindling chain is *remotely possible*. If the TFE valve seat or silicone O-rings ignite, the surrounding aluminum is likely to ignite.

5.1.14 Check Valve CV-2

Check valve CV-2 is the vent-to-tank check valve. Its purpose is to disallow back-pressure to build in the pump, P-1. The valve unseats at 115 psig (0.79 MPa).

5.1.14.1 Material Flammability of Metals and Soft Goods

The metals in this check valve include a 316 stainless steel body and a 17-4 PH poppet. At 115 psig (0.79 MPa), these metals are *nonflammable*. There are no polymers in this check valve.

5.1.14.2 Ignition Mechanisms

All ignition mechanisms were considered *almost impossible* as its operating environment is not severe.

5.1.15 Check Valve CV-1

Check valve CV-1 is located at the outlet to the hospital oxygen supply. It prevents backflow and contaminant from entering the ROSE I. The worst-case operating pressure of the check valve is 90 psig (0.62 MPa).

5.1.15.1 Material Flammability of Metals and Soft Goods

The metal parts of this check valve include a 302 stainless steel spring, and a brass body and poppet. At these low pressures, the metals are *nonflammable*. The polymers include Buna-N O-ring seal. Buna-N is considered *flammable*, even at these low pressures.

5.1.15.2 Ignition Mechanisms

As in check valve CV-2, all ignition mechanisms are considered *almost impossible.*

5.1.16 Connections C-1, C-2, C-6

Connections C-1, C-2, and C-6 provide quick connections from the ROSE I to the medical oxygen and vacuum respectively. The maximum pressure is 115 psig (0.79 MPa).

5.1.16.1 Material Flammability of Metals and Soft Goods

The body of the quick connect is stainless steel, which *nonflammable* in this operating environment. The soft goods are Buna-N, which is a *flammable* material in this environment.

5.1.16.2 Ignition Mechanisms

All ignition mechanisms were found to be *almost impossible* in this analysis.

5.1.17 Connection C-5

Connection C-5 is the high-pressure oxygen supply connection of the ROSE I. The worst-case pressure to this component is 2500 psig (17 MPa) from supply valve V-13. The temperature is approximately ambient.

5.1.17.1 Material Flammability of Metals and Soft Goods

The metals in the quick connect include 316 stainless steel snap rings and springs and a stainless steel body. At this high pressure, 316 stainless steel is considered *flammable*. The polymers include Virgin TFE and filled TFE seals, packings, and back-up rings, as well as TFE internal lubricant. These soft goods are *flammable* in this configuration.

5.1.17.2 Ignition Mechanisms

The only ignition mechanism of concern is contamination. Contamination resulting from unclean hoses may lead to *possible* ignition hazards in the system. It is recommended that the connection cap is placed on the component immediately after disconnection to keep the components clean.

Kindling chain is *remotely possible* in connection C-5, but is controlled by the system configuration.

5.1.18 Pump P-1

Pump P-1 delivers high-pressure LOX to the powered heat exchanger, HX-2. The maximum operating pressure for the pump is 3500 psig (24 MPa). History of use data show that 20 of these pumps have been operating in oxygen over the last five years. This component was designed in the early 1960's, and no fires are known to date.

5.1.18.1 Material Flammability of Metals and Soft Goods

The metals in the pump include a 316 stainless steel body and poppet, a 440 C stainless steel sleeve, a bronze head on the pump shaft, and a 440 C stainless steel ball. Stainless steel is *flammable* at this worst-case pressure. The soft goods in the pump include bronze-filled TFE split rings and back-up rings. Both are *flammable* in this environment.

5.1.18.2 Ignition Mechanisms

Frictional heating presents a *remotely possible* ignition hazard induced by the dynamics of the pump. Wear of TFE split rings could cause rubbing in the cylinder. The inherent low velocities of the LOX flow make particle impact ignition *almost impossible*.

Kindling chain is *remotely possible* as polymers, if ignited, could ignite the surrounding stainless steel.

5.1.19 Heat Exchanger HX-1, HX-2

HX-1 is a passive heat exchanger which heats cold GOX to ambient temperature. It is analyzed simply as a bundle of bent tubing. The worst-case pressure is 120 psig (0.83 MPa), protected from overpressure by RV-4. Heat exchanger HX-2 is also a multi-pass, bent tubing unit, but with heating elements installed to heat the aluminum block. HX-2 has a maximum pressure of 2250 psig (15.5 MPa), coming from the high-pressure pump. The flowrate is approximately 1500 ft^3/hr (42.5 m3/hr) and the velocity is on the order of 121 ft/s (36.9 m/s) in gas. Only the high-pressure heat exchanger will be analyzed as it represents the worst-case operating environment.

5.1.19.1 Material Flammability of Metals and Soft Goods

The metals include stainless steel tubing inside of an aluminum casting. At the pressure indicated, the metals are considered *flammable*. There are no soft goods in the heat exchanger.

5.1.19.2 Ignition Mechanisms

The only ignition mechanism of concern is that of particle impact in high-velocity gas. Ignition is *remotely possible* from particles impacting the 90-degree bends in the stainless steel tubing. The maximum velocity of the gas is calculated to be 121 ft/s (37 m/s). Particles have been shown to ignite 316 stainless steel at velocities of 150 ft/s (50 m/s) (Williams, Benz, and McIlroy 1988). This hazard could be eliminated entirely if a filter were strategically placed in the system to catch particles.

If the stainless steel tubing ignites, the aluminum casting would be highly vulnerable to ignition. Therefore, ignition as a result of kindling chain is *probable* if the stainless steel tubing ignites.

5.1.20 Burst Disc BD-1

Burst disc BD-1 is used to prevent overpressure of the low-pressure oxygen line. It is a bulged-disc configuration which bursts in a pedal arrangement to restrict flow. The burst pressure is 165 psig (1.1 MPa).

5.1.20.1 Material Flammability of Metals and Soft Goods

The burst disc has a brass elbow and disc. The metals are *nonflammable* at the maximum burst pressure. There are no polymers in this component.

5.1.20.2 Ignition Mechanisms

Mechanical impact occurs but the metals are *nonflammable* at the pressure specified. All other ignition mechanisms are *almost impossible*.

5.1.20.3 Secondary Effects

If the burst disk failed, some secondary effects should be considered. First, metallic particles might be released downstream creating a particle impact hazard. In this scenario, all downstream fittings are *nonflammable*. Therefore, the ignition hazard associated with this incident is *almost impossible.*

5.2 HOBS System

The HOBS is shown in Figure 4. Many components of this system are similar to components on the ROSE I. The operational procedures and conditions of the HOBS were considered and, in some cases, the HOBS components were analyzed only by similarity to their counterparts in the ROSE I. Thus, they were not considered in the HOBS analysis. Table 1 shows the components of the HOBS that were analyzed by similarity to their ROSE I counterparts.

Table 1
HOBS Components Analyzed in the ROSE I

Not Analyzed HOBS Component	Analyzed ROSE I Counterpart	Justification
Regulator R-1 (hospital use regulator)	Regulator R-1 (medical oxygen)	Same configuration. Equal or less pressure than ROSE I
Regulator R-2 (secondary ROSE I regulator)	Regulator R-1	Same configuration. Equal or less pressure than ROSE I
Pressure gauge PI-1 (primary pressure indicator)	PI-1 (oxygen delivery)	Same gauge as on ROSE I
Pressure gauge PI-2 (secondary ROSE I)	PI-2 (tank gauge)	Same gauge as on ROSE I
Pressure gauge PI-5 (hospital oxygen supply)	PI-2	Same gauge as on ROSE I
Pressure gauge PI-4 (vacuum pressure)	PI-1, PI-2, on ROSE I PI-5 on HOBS	Equal or less severe conditions than on ROSE I
Pressure gauge PI-8 (Left manifold pressure leading to the "D" cylinders)	PI-3 (gauge on pressure switch, PS-1)	Same 0-5000 psi (0-34.5 MPa) gauge
Pressure gauge PI-9 (Right manifold pressure leading to the "D" cylinders)	PI-3 (gauge on pressure switch, PS-1)	Same 0-5000 psi (0-34.5 MPa) gauge

In considering the HOBS on a system level, care should be taken to ensure the system is free of contamination. This can be done by performing visual inspections of often-removed components and connections, as well as avoiding any hydrocarbon oil or grease during servicing.

Chart 2 shows a summary of the hazards analysis that was performed on the HOBS. The analysis of each component is discussed below.

Chart 2

Summary of Oxygen Hazards Analysis for the HOBS

Hospital Oxygen Backup System (HOBS)	Metals	Soft Goods	Frictional Heating	Adiabatic Compression	Mechanical Impact	Particle Impact	Mechanical Stress	Static Discharge	Electrical Arc	Chemical Reaction	Resonance	Other Ignition Mechanisms	Kindling Chain	Secondary Effect	Reaction Effect
Pressure Indicator: PI-3, PI-6, PI-7	N	-	0	0	0	0	0	0	0	0	0	1	0	-	C
Flexible hose: 1, 2 (O2 Cylinders)	F	F	0	1	0	0	0	0	0	0	0	0	2	-	C
Flexible hose: 3 (High Pressure Fill)	F	F	0	0	0	0	0	0	0	0	0	0	2	-	C
Flexible hose: 4 (Hospital Supply)	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C
Regulator: R-3	F	F	0	2	0	1	0	0	0	0	0	0	3	-	C
CGA 540 Cylinder Valve	N	F	0	0	0	0	0	0	0	0	0	0	1	-	C
Valves: V-1, V-2, V-4, V-5, V-6	N	F	0	1	0	0	0	0	0	0	0	0	0	-	C
Valves: V-3 A-H, V-7, V-8	N	F	0	1	0	1	0	0	0	0	0	0	0	-	C
Check Valve: CV-1, CV-2, CV-3	N	F	0	0	0	0	0	0	0	0	0	1	0	-	C
Check Valve: CV-4	F	F	0	1	0	0	0	0	0	0	0	0	1	-	C
Relief Valve: RV-1	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C

5.2.1 Pressure Indicators PI-3, PI-6, PI-7

PI-3 indicates the HOBS supply pressure. PI-6 and PI-7 indicate the left and right manifold pressure, respectively. Each of these gauges are 0 - 4000 psi (0 - 27.6 MPa) standard Bourdon tube gauges. The maximum operating pressure of these gauges is 2500 psig (17 MPa).

5.2.1.1 Material Flammability of Metals and Soft Goods

The metals found in the Bourdon tube and corresponding fittings are considered *nonflammable* in the worst-case operating condition. There are no soft goods in these gauges.

5.2.1.2 Ignition Mechanisms

The only ignition mechanism considered to be a potential hazard is the scenario of contamination in the gauge. If this happens, it is *remotely possible* for a fire to occur in the gauge as a result of rapid compression.

5.2.2 Flexible Hoses 1 and 2 (O_2 Cylinders)

The following is a general note that applies to all flexible hoses on the HOBS: It is recommended that operating procedures specify that the ends of all flexible hoses are to be inspected for cleanliness before connection.

The flexible hoses connected to the "D" cylinders are labeled flexible hose 1. The flexible hoses connected to the "H" cylinders are labeled flexible hose 2. Both of these hoses have a maximum operating pressure of 2500 psi (17 MPa).

5.2.2.1 Material Flammability of Metals and Soft Goods

The metals include stainless steel and the soft goods include a Teflon liner in the stainless steel sheath. Both the metals and the polymers are *flammable* at the given worst-case pressure.

5.2.2.2 Ignition Mechanisms

Adiabatic compression was considered a *remotely possible* source of ignition. The critical length distance piece on the CGA fittings was calculated as recommended in ASTM STP 986 (Barthelemy and Vagnard 1988). It was determined that the distance piece given on the flexible hose is sufficient.

If the Teflon liner is ignited, the stainless steel is likely to burn. Therefore, a kindling chain ignition hazard is considered *possible*.

5.2.3 Flexible Hose 3 (High-pressure Fill)

Flexible hose 3 is a high-pressure hose connected to the HOBS high-pressure fill line. The worst-case operating pressure is 2500 psig (17.2 MPa).

5.2.3.1 Material Flammability of Metals and Soft Goods

The metal sheath is stainless steel and the liner is Teflon. Both the metals and soft goods are *flammable* in the worst-case environment.

5.2.3.2 Ignition Mechanisms

The only ignition mechanism discussed, but not evaluated, is that of unrestrained flexible hoses. It is recommended that procedures be written to protect and restrain flexible hoses. Restraining flexible hoses is a standard practice, especially in high-pressure applications.

As is the case with other lined flexible hoses, if the Teflon liner ignites, the stainless steel is likely to burn. Therefore, the kindling chain ignition hazard is *possible.*

5.2.4 Flexible Hoses 4 (Hospital Supply)

The flexible hoses that connect the HOBS to the hospital oxygen supply are labeled with a 4. These are low-pressure hoses, with a maximum pressure of 115 psig (0.79 MPa).

5.2.4.1 Material Flammability of Metals and Soft Goods

Each of these hoses is stainless steel with a Teflon liner, similar to those previously discussed. At the low operating pressure specified, the stainless steel is considered *nonflammable*. The Teflon, however, is still *flammable.*

5.2.4.2 Ignition Mechanisms

The only ignition mechanism of concern is the same as with flexible hose 3. Though the ignition mechanism was not analyzed, it is recommended that the flexible hose be restrained, even at this low pressure, for protection and safety. All other ignition mechanisms are considered *almost impossible.*

5.2.5 Regulator R-3

Regulator R-3 is the HOBS supply regulator. It regulates a maximum inlet pressure of 2250 psig (15.5 MPa) down to 75 psig (0.52 MPa). It is recommended that, for all system regulators, extreme care be taken to avoid contamination. Hydrocarbon oil or grease during servicing should be avoided at all times. In addition, inspection of pieces which are removed for servicing is necessary.

5.2.5.1 Material Flammability of Metals and Soft Goods

The metals in regulator R-3 include a brass body, spring and stem, and a stainless steel plunger. At the worst-case operating pressure, stainless steel is considered *flammable.* The soft goods include a nylon seat and a neoprene diaphragm, which are also *flammable.*

5.2.5.2 Ignition Mechanisms

Adiabatic compression in regulator R-3 is considered a *possible* ignition mechanism. Regulator R-3 can be exposed to rapid compression if any "H" cylinder valves are opened when valves V-2 or V-1 are open. History of use indicates that no fires have occurred in this system during three years of operation. The proven history of use for this component makes its risk level acceptable. Additionally, if component tests are performed on this regulator,

and the data confirms its resistance to ignition by adiabatic compression in this environment, then the *possible* ignition rating may be reduced. Particle impact is a *remotely possible* ignition mechanism if the regulator is contaminated.

Kindling chain is a *probable* ignition hazard if the nylon seat of the regulator ignites. The neoprene diaphragm and surrounding metals are susceptible to ignition.

5.2.6 CGA 540 Cylinder Valve

The valves used on the "H" size oxygen cylinders of the HOBS are of a CGA 540 configuration. The worst-case operating pressure in these cylinders is 2250 psig (15.5 MPa).

5.2.6.1 Material Flammability of Metals and Soft Goods

The metal pieces of these valves are fabricated from brass and bronze. These metals are considered *nonflammable* in this operating environment. The soft goods include a nylon seat. Nylon is considered *flammable* in this scenario.

5.2.6.2 Ignition Mechanisms

Adiabatic compression is considered an *almost impossible* ignition hazard, despite the use of nylon as a seat material in these valves. If the manifold is pressurized to 2200 psig (15 MPa), and one of the high-pressure cylinder valves, V-3, is opened, the slug of gas in the "H" cylinder flexible hose may be rapidly compressed. To determine the severity of this ignition mechanism, the distance piece on the CGA valve was evaluated per ASTM STP 986 (Barthelemy and Vagnard 1988). The final volume of gas in the connecting flexible hose, when compressed from 1 atmosphere pressure to 2200 psig (15 MPa), is only 0.05 in^3 (0.82 cm^3). This volume is compared to the internal volume of manual valve V-3 at the flexible hose connection, 0.62 in^3 (10.2 cm^3). Because the valve volume is more than an order of magnitude larger than the compressed gas volume of the flexible hose, rapid compression will not create enough heat to ignite the nylon seat of the valve.

Kindling chain is a *remotely possible* ignition hazard for the CGA valves. If the nylon seat were to ignite and burn, the chances of igniting the surrounding metals are only *remotely possible*.

5.2.7 Manual Valves V-1, V-2, V-4, V-5, V-6

Manual valves V-1 and V-2 are the left and right high-pressure manifold isolation valves, respectively. Valves V-4 and V-5 are the left and right vacuum isolation valves, respectively. Valve V-6 is a vent valve for the manifold. Each of these valves is a globe-type configuration with similar materials of construction. The worst-case operating pressure is 2250 psig (15.5 MPa).

5.2.7.1 Material Flammability of Metals and Soft Goods

The metals of these valves include a brass stem and body. Brass, under these operating conditions, is considered *nonflammable*. The soft goods include a Kel-F valve seat, which is *flammable* in these conditions.

5.2.7.2 Ignition Mechanisms

Adiabatic compression is the only ignition mechanism considered a potential hazard. The scenario of rapid compression on these valves is similar to that discussed for regulator R-3 in terms of history and experience, but the configuration and material choices for these valves are superior. For this reason, adiabatic compression is considered a *remotely possible* ignition hazard. Particle impact was evaluated on the vent valve, V-6, and considered an *almost impossible* ignition hazard. The gas flowing through V-6 will go sonic as it vents to atmosphere, but the materials which would see a potential impact are brass. Brass is considered *nonflammable* in this environment.

5.2.8 Manual Valves V-3A through V-3H, V-7, V-8

Manual valves V-3A through V-3H are the high-pressure cylinder valves. Valves V-7 and V-8 are the left and right manifold isolation valves for the "D" cylinders, respectively. Each of these valves is built to CGA specifications. The worst-case operating pressure is 2500 psig (15.5 MPa).

5.2.8.1 Material Flammability of Metals and Soft Goods

These valves are similar to the other CGA valves analyzed as they have brass stems and bodies and nylon seats. The metals are *nonflammable* and the soft goods are *flammable.*

5.2.8.2 Ignition Mechanisms

Adiabatic compression is considered *remotely possible* as these valves can be rapidly pressurized while closed, exposing the nylon seat. However, the configuration of these valves protects the seat against rapid compression and the history of use is substantial in oxygen. Particle impact is also considered a *remotely possible* ignition source. Assembly-generated particles may be present in the flow stream. However, the valve seat is well protected in this configuration, which reduces this hazard.

5.2.9 Check Valves CV-1, CV-2, CV-3

Check valve CV-1 is for the primary ROSE I line, downstream of regulator R-1. Check valve CV-2 is for the secondary ROSE I line, downstream of regulator R-2. Check valve CV-3 is for the HOBS supply line, protecting regulator R-3 from reverse flow. The worst-case pressure used to evaluate these check valves is 115 psig (0.79 MPa).

5.2.9.1 Material Flammability of Metals and Soft Goods

The metal pieces in these valves include a 316 stainless steel body, spring, and poppet. The metals are considered *nonflammable* in this environment. The soft goods include Viton®[1] body seals and Teflon back-up rings, both of which are *flammable.*

5.2.9.2 Ignition Mechanisms

Particle impact was evaluated as a potential ignition mechanism. Particles can impact the stainless steel poppet in the normal flow direction at velocities of approximately 90 ft/s (27 m/s). This velocity is low for particle impact ignition, but stainless steel is not *flammable* in this scenario. Thus, particle impact is considered an *almost impossible* ignition mechanism. Another ignition mechanism occurs if particles are ignited upon impacting the stainless steel disk. In this scenario, ignition of the Viton seat is *remotely possible.*

5.2.10 Check Valve CV-4

Check valve CV-4 is a uniquely designed cartridge-type valve. It is used to prevent backflow on the HOBS fill line. It has a high-pressure maximum operating condition of 2250 psig (25.5 MPa).

5.2.10.1 Material Flammability of Metals and Soft Goods

The metals on CV-4 include a stainless steel body, plunger, and spring. The sealing material is Teflon. At the highest operating pressure, both the metals and polymers in the check valve are considered *flammable.*

5.2.10.2 Ignition Mechanisms

Adiabatic compression is the ignition mechanism of most concern. Several factors reduce this ignition hazard to *remotely possible.* According to pneumatic impact data, TFE (Teflon) has ignited at 3000 psig (20.7 MPa), but not at 2500 psig (17.2 MPa) (WSTF # 80-13068).[2] At 2250 psig (25.5 MPa), this application is less severe. Also, check valve CV-4 has a configuration which protects the Teflon from direct impingement in the case of rapid pressurization. Finally, the pressurization rate is estimated to be slower than 50 ms, reducing the risk of ignition. Particle impact was considered a potential hazard, but the gas velocity through the valve is only 8 ft/s (2.4 m/s), too low to ignite particles. Therefore, particle impact ignition is considered *almost impossible.*

Kindling chain ignition is *remotely possible* if the Teflon seat is ignited, threatening the ignition of the surrounding stainless steel.

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[1] Viton is a registered trademark of 3M.

[2] In-house report. NASA Johnson Space Center White Sands Test Facility, Las Cruces, NM, 1980.

5.2.11 Relief Valve RV-1

Relief valve RV-1 acts to protect the HOBS connection manifold from overpressure. The relief valve is set for 150 psig (1.0 MPa).

5.2.11.1 Material Flammability of Metals and Soft Goods

The materials of construction for RV-1 include a brass body, seat retainer, and spring holder, and a stainless steel spring. The seat disc is fluorosilicone. At the given worst-case conditions, the metals are considered *nonflammable* and the polymers are *flammable*.

5.2.11.2 Ignition Mechanisms

All ignition mechanisms were considered *almost impossible* for this component. The pressurization rate is too slow to ignite the polymer and cause ignition by adiabatic compression. As a worst-case example, nylon has been shown to pass pneumatic impact tests in this environment (0 ignitions out of 20 impacts at 500 °F (260 °C) and 500 psig (3.4 MPa)) (WSTF # 81-14395).[1]

5.3 PODS System

A block diagram of the PODS is shown in Figure 5. Oxygen is supplied to the systems through the ROSE I or HOBS units, or from a back-up oxygen cylinder. A low-pressure alarm signals when the gas pressure falls below the set minimum of 40 psig (0.3 MPa). Oxygen is distributed to the individual patients' beds through a flexible hose and a flowmeter. The maximum operating pressure from the outside components in the PODS is 60 psi (0.4 MPa).

Chart 3 shows a summary of the oxygen hazards analysis performed on the PODS. Each component shown was analyzed and their results are discussed below.

The quick disconnects on the Teflon flexible hoses of the PODS were not considered in this analysis. Their material composition and operating environment are similar to the connections C-1 and C-2 on the ROSE I and, thus, were adequately analyzed as part of the ROSE I.

5.3.1 Flexible Hoses

These are Teflon hoses with stainless steel fittings. The maximum flow through each hose is 2.1 ft^3/min (60 L/min) at a pressure of 60 psig (0.4 MPa).

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[1] In-house report. NASA Johnson Space Center White Sands Test Facility, Las Cruces, NM, 1981.

Chart 3
Summary of Oxygen Hazards Analysis on the PODS

Patient Oxygen Distribution System (PODS)	Metals	Soft Goods	Frictional Heating	Adiabatic Compression	Mechanical Impact	Particle Impact	Mechanical Stress	Static Discharge	Electrical Arc	Chemical Reaction	Resonance	Other Ignition Mechanisms	Kindling Chain	Secondary Effect	Reaction Effect
Flexible hoses	N	F	0	0	0	0	0	1	0	0	0	0	0	+	C
Flowmeter Assembly	N	F	0	0	0	0	0	0	0	0	0	0	0	-	C
Pressure Switch (Alarm)	N	F	0	0	0	0	0	0	1	0	0	0	0	-	C

5.3.1.1 Material Flammability of Metals and Soft Goods

The stainless steel fittings are *nonflammable* at this low pressure, but the Teflon is *flammable* in this environment.

5.3.1.2 Ignition Mechanisms

Static discharge in flowing oxygen can be a valid ignition mechanism in Teflon lines. In this case, ignition from static discharge is only considered to be *remotely possible*. Another ignition mechanism considered, but determined to be *almost impossible*, is any external ignition source that contacts the Teflon hoses such as lasers or other electrical operating tools. Standard medical-ward operating procedures are sufficient to keep this from occurring. Therefore, this is considered to be an *almost impossible* ignition hazard.

5.3.1.4 Secondary Effect

One secondary effect considered is an external leak from the hose into the hospital or a patient's bed. If this happens, an oxygen-enriched environment might result. Upon further analysis, it is concluded that any potential ignition source must be kept away from the hospital beds.

5.3.2 Flowmeter Assembly

The flowmeter assembly consists of a regulator, a rotameter-type flowmeter, and the connection fittings and tubes. The oxygen is supplied at a pressure of 30 to 60 psig (0.21 to 0.41 MPa), then reduced to 15 psig (0.10 MPa) through the regulator. Though analyzed individually, these components are discussed here as one unit.

5.3.2.1 Material Flammability of Metals and Soft Goods

The oxygen-wetted metals inside the flowmeter assembly include brass, chrome-plated brass, and stainless steel. These are considered *nonflammable* at the worst-case operating conditions. The soft goods include Teflon, Buna-N, and Viton. These are considered *flammable* in pure oxygen, even at the low operating pressures.

5.3.2.2 Ignition Mechanisms

All ignition mechanisms are considered *almost impossible*. This flowmeter design has a extensive history of use in many applications. The operating environment is not severe enough to produce oxygen hazards in this component.

5.3.3 Pressure Switch (Alarm)

The pressure switch, or alarm, detects a pressure loss in the Teflon hose. When the supply pressure gets too low, it activates an alarm and a light through an analog signal (microswitch). The pressure switch is set to 40 psig (0.28 MPa) or less.

5.3.3.1 Material Flammability of Metals and Soft Goods

The metal materials of the pressure switch are considered *nonflammable* in this operating environment. The polymers, however, are *flammable* in pure oxygen, despite the low pressure.

5.3.3.2 Ignition Mechanisms

The only ignition mechanism of concern is electrical arc. It is determined, however, that the 110-volt power supply is too low a voltage for a spark to develop. In addition, the metals are considered *nonflammable* in this environment.

5.4 LOX Buffer Storage Tank (BST)

The BST is shown in Figure 6. The BST is a 400-gallon LOX dewar. The operational pressure is 40 psig (0.28 MPa) maximum. The setting on the line relief valve RV-1 is 50 psig (0.34 MPa). The tank has a burst disc too, which is set for 75 psig (0.52 MPa). The BST flow system is similar in design to the ROSE I. Nearly all the components on the BST correspond directly to components on the ROSE I, both in material and configuration (Table 2). Also, the maximum operating pressure of the BST is less severe than that of the ROSE I. Therefore, the analysis of the BST was performed only through comparison to the ROSE I analysis.

Table 2
BST Components Analyzed by Similarity to the ROSE I

BST Component	Similar ROSE I Component
Manual Valve V-3	Manual Valve V-1
Manual Valve V-6	Manual Valve V-1
Manual Valve V-7	Manual Valve V-2
Manual Valve V-8	Manual Valve V-3
Manual valve V-9	Manual Valve V-5
Manual Valve V-10 (Low Pressure)	Manual Valve V-6
Manual Valve V-10 (High Pressure)	Manual Valve V-7
Manual Valve V-12	Manual Valve V-4
Liquid Level Indicator LL-1	Liquid Level Indicator LL-1
Pressure Indicator PI-1	Pressure Indicator PI-2
Regulator R-1	*Roading* Regulator PCV
Regulator R-2	Regulator R-2
Relief Valve RV-1	Relief Valve RV-6
Relief Valves RV-3, RV-4	Relief Valve RV-3
Safety Disc SD-1	Burst Disc BD-1
Pressure Building Coil PBC-1	Pressure Building Coil PBC-2

5.5 High-speed Recharger System

The high-speed recharger is shown in Figure 7. The high-speed recharger is used to fill the oxygen cylinders in a short time frame. It fills eight cylinders in approximately 12 minutes. This component is not located in close proximity to the hospital. Again, similarities exist between this component and the previously analyzed ROSE I. The similarities are shown in Table 3. Because of these similarities, a component analysis will only be done on the LOX pump.

Table 3
High-speed Recharger Components Analyzed by Similarity to the HOBS or ROSE I

High-speed Recharger System Component	Similar Component on the ROSE I
Connector to C-3 on CFS	Connection C-3 on ROSE I inlet
Pressure Indicator	Pressure Indicator PI-3 on ROSE I
Pressure Switch	Pressure Switch PS-1 on ROSE I
Relief Valve	Relief Valve RV-5 on ROSE I
Manual Valve	Manual Valve V-16 on ROSE I

The summary of the oxygen hazards analysis performed on the high-speed recharger LOX Pump is shown in Chart 4. The results of the analysis are discussed in the following sections.

Chart 4
Summary of Oxygen Hazards Analysis on the High-speed Recharger

High-speed Recharger	Metals	Soft Goods	Frictional Heating	Adiabatic Compression	Mechanical Impact	Particle Impact	Mechanical Stress	Static Discharge	Electrical Arc	Chemical Reaction	Resonance	Other Ignition Mechanisms	Kindling Chain	Secondary Effect	Reaction Effect
LOX Pump	F	F	0	0	0	0	0	0	0	0	0	0	0	-	C

5.5.1 LOX Pump

This LOX pump functions identically to the LOX pump, P-1, of the ROSE I. The poppet, however, is constructed of different materials. The history of use for this LOX pump is more extensive than for the ROSE I pump, which is favorable. The maximum operating pressure of the LOX pump is 2250 psig (15.5 MPa).

5.5.1.1 Material Flammability of Metals and Soft Goods

The materials in this pump are identical to those in P-1 of the ROSE I, except for the poppet. Carbon-filled Teflon is used for the poppet seal (check valve seat), in place of the 440 C stainless steel ball used in the pump on the ROSE I. Viton seals also exist on the vacuum. At the maximum operating pressure, both the metals and the polymers are considered *flammable*.

5.5.1.2 Ignition Mechanisms

All ignition mechanisms were analyzed and found to be *almost impossible* for this pump.

6.0 Recommendations

From the oxygen hazards analysis performed on the PCI Genox CT-1 Oxygen Generation and Distribution System, it was determined by the WSTF Oxygen Hazards Analysis Team that no major oxygen hazards exist in this system to prevent its use in the given environments. However, several recommendations are made that, if implemented, will enhance the system's resistance to an oxygen fire and provide a safer operating environment.

1. Contamination is a major cause of fires in oxygen systems. The Genox CT-1 Oxygen Generation and Distribution System has some locations where contamination is likely. The following is recommended:

   a) It is recommended that maintenance procedures be implemented to periodically evaluate the contamination level of the LOX tank on the ROSE I. There exists a possibility of contamination build-up in the LOX tank from repeated filling and venting (impurities in the LOX), as well as if the PCV component failed (air/moisture contamination).

   b) It is recommended that procedures dictate that the cap to connection C-5 on the ROSE I be placed back on the connection immediately after disconnection. This recommendation applies to all system flexible hose connections used in oxygen service to maintain cleanliness.

   c) It is recommended that operating procedures specify that the ends of all flexible hoses are to be visually inspected for cleanliness before connecting to any system for oxygen service.

   d) It is recommended that, for all system regulators, care be taken to avoid contamination when servicing. Hydrocarbon oil or grease during servicing should be avoided at all times. Visual inspections should be performed before installation.

   e) It is recommended, but not mandated, that system filters be considered in places where particulate generation is most likely (commonly assembled and disassembled components), or where particle impact ignition is most likely (see individual component hazards analysis charts for particle impact ignition hazards).

   f) As a secondary recommendation, but again not mandated, to prevent particulate build-up in Bourdon tube pressure gauges, consider implementing Bourdon tubes with bleed ports. This allows for thorough cleaning of these gauges. Also, for increased ignition resistance, consider changing all stainless steel Bourdon tube gauges to brass.

2. As an issue of safety, it is recommended that procedures be written to protect and restrain flexible hoses on both the ROSE I and the HOBS. Restraining flexible hoses is a good safety practice, especially with high-pressure flexible hoses.

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